BUS AND RAIL DEMAND MODELS FOR THE COLOMBO METROPOLITAN REGION

Saman J. Widanapathiranage and Amal S. Kumarage
Department of Civil Engineering, University of Moratuwa, Sri Lanka.

Paper Presented at the
Engineering Research Unit Symposium,
University of Moratuwa, Sri Lanka

August 2003
BUS AND RAIL DEMAND MODELS FOR THE COLOMBO METROPOLITAN REGION

Saman J. Widanapathiranage and Amal S. Kumarage
Department of Civil Engineering, University of Moratuwa, Sri Lanka.

ABSTRACT

Demand estimation models attempt to capture the traveler behavior and the characteristics of a transportation system. Bus and rail models developed in this paper are intended to capture the manner in which the transportation scenario in the Colombo Metropolitan Region (CMR) would change to exogenous conditions. Each type of travel has a corresponding characteristic related to its generation and attraction that can be identified in terms of a set of socioeconomic variables of the geographic zones between which travel occurs.

These models have been calibrated using data from various surveys done within the CMR during the period 1996 to 1998. These models attempt to explain, (a) bus travel demand, (b) railway travel demand using ordinary tickets, (c) railways travel demand using season tickets and (d) total public transportation demand. In these models, the impedance to travel is expressed in a generalized form, which includes fare, waiting time, transfer time and travel time. In the case of the rail model, it was seen that access to the railway was also a significant parameter. This was represented by the proportion of the area of the DSD that is within 3 km from a primary station. Another significant variable in the models was the effect of direct services between attraction zones and generation zones by either both bus and rail as opposed to having transfers to travel. A variable which represents the density of housing in these models was found to reduce inter zonal travel trips by between 8% to 30% with increasing density, possibly to account for the ‘self-containment’ within the zone, where the possibility that generation and attraction are both found within the same zone, thus reducing the amount of inter zonal travel.

A set of travel demand models for bus, rail and total public transport have been successfully calibrated at a 5% level of significance of the model variables, with Coefficients of Correlation (R-square statistic) of between 70% to 80%.

BACKGROUND

The study concentrates on the Colombo Metropolitan Region (CMR). It is made up of 33 Divisional Secretary Divisions (DSD’s) (See the map in Annexure 01). The area of the CMR is identical to the Western Province and extends from Walallawita DSD in the South, to Negombo DSD in the North, Hanwella DSD in the east and Colombo DSD in the West. The CMR has three districts Colombo, Gampaha and Kalutara.

The CMR population was estimated as 5.4 million in 2001 (Nanayakkara, 2001). Table 1 shows the variation in population densities by district with Colombo showing a significantly higher density. With increasing densities in Colombo, the employees tend to reside in peripheral areas where land is available and to commute longer distances to Colombo City.

Table 01: Population Density in the CMR
According to data available at the Transport Engineering Division of the University of Moratuwa the daily passenger travel within the CMR consisted of 2.3 return trips between different DSDs, which were distributed across 60% by buses, 7% by railway, 28% by private vehicles and 5% by goods vehicles.

Public bus services are operated by both the State sector and private sector in all DSD’s of the CMR and in 1998, produced about 1.5 millions of two way inter DSD trips per day. However, the quality of the service is poor with overcrowding, not maintaining a proper schedule and travel times particularly by private bus operators.

There is considerably lower demand for railway travel when compared to the more popular bus service. This is mainly due to poor reliability of service, frequent delays due to poor maintenance of rail tracks, inadequate signalling and rolling stocks (National Transport Policy, 2000). Most railway trips are concentrated towards Colombo from the 19 DSD’s the railway serves. It carries around 0.1 millions of inter DSD trips per day. According to the railway department, about 70% of the travelers use monthly season ticket for travel with a discount of 40% of the cost of the ordinary ticket. The employees in most state sector institutions enjoy this facility where the employer pays about 75% of this cost. The level of the discount encourages more state sector employees to use rail as an alternative choice for mode of travel.

The future planning of public transportation requires a scientific basis and a quantitative analysis of passenger trip demand for bus and railway travel. Transport demand models are used for this purpose. There are a few models to be found in literature (Wijesundera, 2001, Wijeratne, 2001) to estimate inter DSD trip demand in the CMR. In 1998, a set of multi-modal models for bus and rail were calibrated to estimate inter DSD travel demand. The socio economic variables used in those models have been population, household size, vehicle ownership rate and product of job-population together with the impedance variable of generalized cost of travel. The product of population was the main determinant of travel in the model. In 1999, a set of models for railway ordinary ticket and season ticket travel demand estimation were calibrated (Kumarage, 1999). The socioeconomic variables used in those models have been population, vehicle ownership rate and railway accessibility as a dummy variable. It was found that the different models did not have a consistent set of variables. Even when the variables were consistent, the forms in which they were represented in the different models were inconsistent. Hence, there is a need to formulate a set of models that have a better relationship to each other and is more accurate in as a whole.

### OBJECTIVES & METHODOLOGY
The aim of this paper is to present a set of transportation demand estimation models that are build in according to a common format to estimate bus and railway total inter trip demand between DSD’s in the CMR. These models have been calibrated using data from various surveys done within the region during the period 1996 to 1998. This paper discusses following models to explain,

(a) Bus travel demand.
(b) Railway travel demand using ordinary tickets.
(c) Railway travel demand using season tickets.
(d) Total public transportation demand.

Calibration was through Least Squares estimation using the statistical software SPSS™+V 10.0. The calibration investigated a number of independent variables that were expected to have causal effect on travel between the dependent variable which had daily travel between any two DSD's and a number of dependent variables that represented the socioeconomic, demographic and transport characteristics. There was no complete set of data for all DSD’s. As such, models were calibrated using the DSD’s for which complete data sets were available and validated using the socio economic variables for remaining sets. The year 1998 was taken as the base year and all other socio economic data was projected to that year by applying historic growth rates. The employment variable was prepared by applying the following assumptions,

- Employment within the CMR is by people residing within the CMR ,
- The sub category called self-employment includes all the private sector jobs.
- Agricultural employees reside and work in the same DSD’s.
- That 2% of the employees have migrated from other regions and reside within the CMR.

The employed population in each zone- as opposed to population used in earlier models, was seen as the best fitting variable to explain the gravity formulation. Wachs et al. (1993) in South California had found that long distance trips had grown over the years due to growth of employment. Kitamura et al. (1997) found that person trip generation and attraction is largely determined by demographic and socioeconomic characteristics and is not strongly associated with the housing densities. Mc Nally and Kulkarni (1997) shown that income variables explain the differences in number of trips and mode choices. Chunlin at el. (1998) studied the relationship of employment and housing density responds to typical characteristics of the development of urban form and concluded that, employment provides better transportation networks and more efficient investments on the existing network to provide the residents a better place to live and work. Gerald (1998) however describes that higher employment population growth may result the increase in traffic congestion cost in dense metropolitan regions.

**BUS DEMAND MODEL**
Bus transportation is popular in all DSD’s due to direct services provided between residential areas and employment area, relatively high frequency leading to comparatively less waiting time for trips and the lower bus fares compared to private travel. Average bus fares for inter passenger trips in 1998 was 0.44 Rs. per km. calculated using data available at the Transport Engineering Division of University of Moratuwa.

The bus demand estimation model as shown in the Equation 01, indicates (a) the employed population and (b) housing unit density in each DSD’s as being the primary determinants of the demand for travel between the relevant DSD’s together with an exponential variable that indicates direct trips and the generalized cost of travel. The model has been calibrated using 438 cases of inter DSD travel observations and showed a multiple correlation coefficient or R-square of 72.10%.

$$B_{ij} = 0.255 * \frac{E_{ij}^{0.860} * e^{0.854\cdot BT}}{HD_{ij}^{0.197} * BGC^{2.562}}$$

Where:
- $B_{ij}$ = Bus passenger trips between $i^{th}$ and $j^{th}$ zone per day in both directions.
- $E_{ij}$ = Product of employed population residing in $i^{th}$ and $j^{th}$ zone.
- $HD_{ij}$ = Product of the housing density of $i^{th}$ and $j^{th}$ zone, where housing density is given as housing units per sq. km. The housing unit defined as a single occupant or multi occupant permanent house in the DSD.
- $BGC$ = Generalized travel cost of bus in Rupees to travel between $i^{th}$ and $j^{th}$ zone given as, the sum of bus travel cost, waiting time cost and cost of in-vehicle travel time.
- $BT$ = Selected bus travel route between $i^{th}$ and $j^{th}$ zone is a direct (1) or indirect (0).

The employed population is a sub set of the total population in each DSD’s. But it is this proportion of the population that determines to a large extent the travel that is generated and attracted to that zone, which is largely related to work and business purposes. Infact, the land use variable of housing units per square kilometer, represents the transportation interaction characteristic. When housing density increases within a DSD, the population residing within that zone has a better prospect of finding jobs and other needs within the same DSD. The variable to consider the existence of a direct bus service shows that the passenger demand doubles when there is a direct bus route between any two DSD’s.

In terms of application impacts, the model shows that if the product of employee population increases by 10%, then bus passenger trips increase by 5.8 %. When housing density doubles (i.e. without a corresponding increase in employed population) bus passenger trips reduce by 8 %. However, when both employment and housing units increase it may result in a growth in the demand for inter DSD travel. Bus generalized cost calculation explain in the Box 01, included waiting time, travel time, transfer time based on data in 1998. Value of time is an important factor that calculated based on hourly income rate of the passenger, trip purpose of the passenger and quantum of travel time saved.
Box 01. The Calculation of Bus Generalized Cost in Rupees.

**Example: Travel between Kesbewa DSD to Nugegoda DSD.**

- **Normal travel time** = 0.07 hours. Assume 0.2 hours needs to derive actual travel time to travel between centroid of DSD’s.
- **Calculated bus travel time** (B_time) = (0.07 + 0.2) = 0.27 hours.

- Assume **bus fair** (B_fair) = 2.50 Rs. + 0.50 Rs. * 10 (Bus distance in km.) = 7.50 Rs.
- **Value of Time** (VOT) = 10.83 Rs. (is defined by Kumarage, 1999 as the average value of time for passenger by mode of transport is calculated based on, hourly income rate of the passenger, trip purpose of the passenger and quantum of travel time saved)
- **Bus waiting time** = 8*0.5*2.5 = 0.17 hours. (Assume headway is 8 minutes and waiting time is ½ of headway)
- **BGC = B_fair + B_time * VOT + Waiting time * VOT**
  \[ = 7.50 + 0.27*10.83 + 0.17*10.83 = 12.27 \text{ Rs.} \]

The rail models were calibrated in two steps by considering ordinary ticket travel and season ticket travel separately. The results of these two modeling efforts is shown in Equation 2 and 3 respectively. These achieved multiple correlation coefficients (R-square) of 80.14% and 77.69% respectively when 528 cases of inter DSD observations were used for calibration.

The access to the railway appears to be a primary factor for rail travel. In 1998, the cost of an average ordinary ticket was Rs 0.25 per km while season tickets were Rs 0.125 per km. Presently, rails fares are considerably less than bus fares for the same distance of travel as they have not been changed since 1996. The value of time and waiting time are also sensitive factors for rail travel which are included in the generalized cost for rail travel. The calculations are shown in the Box 02.

\[
R_{ij}^O = 1.199 \times 10^{-5} * E_{ij}^{1.456} * e^{[1.823RT+2.740RA_{ij}]} / HD_{ij}^{0.795} * ROGC^{2.512} \tag{2}
\]

\[
R_{ij}^S = 3.395 \times 10^{-10} * E_{ij}^{1.898} * e^{[1.622RT+2.858RA_{ij}]} / HD_{ij}^{0.705} * RSGC^{2.745} \tag{3}
\]

Where: \( R_{ij}^{O,S} \) = Railway ordinary or season ticket passenger travel between \( i \)-th and \( j \)-th zone.

\( RT = 1 \) if there is a direct rail route between \( i \)-th and \( j \)-th zone, 0 if otherwise.

\( ROGC, RSGC \) = Generalized travel cost of ordinary ticket or season ticket trip in Rupees to travel between \( i \)-th and \( j \)-th zone given as the aggregate of rail travel cost, waiting cost and access and egress cost.

\( RA_{ij} \) = Degree of accessibility to rail stations in the respective \( i \)-th and \( j \)-th zone given as the average rail catchment area in the DSD per sq. km.

Box 02. Calculation of Railway Generalized Cost in Rupees.
The primary socioeconomic variable in the rail model is also the product of employed population of the two DSDs. Its fit however is more sensitive than the bus model as demonstrated by the higher coefficients of 1.898 and 1.456 for rail and 0.860 for the bus model. One possible reason for this may be that most commuters who have lower incomes travel by train due to the lower fare. In addition the coefficient for Housing unit density is also considerably higher in the rail model when compared to the bus model.

The output form the model indicates that when the density of housing doubles, trips by rail reduce by 42% for ordinary ticket travel and 37% for season ticket travel. In the case of rail accessibility there is a high sensitivity where accessibility when improved by 10%, translates to an increase in rail travel by 16% for ordinary tickets and 19% for season tickets.

TOTAL PUBLIC TRANSPORTATION DEMAND MODEL

A separate model for total demand estimation of public transport was calibrated using 439 cases of inter DSD travel observations. This model had a multiple correlation coefficient (R-square) of 73.89%. The product of employed population and housing density variables showed a good fit to the model together with an exponential function of direct routing and the product of square roots of DSD’s areas as a variable. In this model, the product of square root of the DSD’s area is taken in order to identify travel that occurs between DSDs when the distance between DSDs is small when compared to the area of any of the DSDs. For example, people residing within a small DSD such as Nugegoda, may very well travel to Colombo DSD for even most basic needs simply because it is closer to get to destinations within Colombo DSD than most possible
destinations within Nugegoda DSD. Direct travel rout choice is also a special attribute since many travelers likely to travel on these routes. As shown below the availability of direct public transport services between any two DSDs also contributes to an increase in trips.

The impedance variable for travel such as the minimum generalized travel cost used in the model calibration is abstracted as the minimum of the generalized travel cost of bus, rail ordinary ticket and rail season ticket travel. The product of employed population and density of housing variables also fit into this model together with the dummy variable representing direct bus and rail routing. The model was calibrated using 439 case of inter DSD travel observations and the results are shown in Equation 4.

\[
T_{ij} = 0.277 * e^{0.068} * e^{0.774BT + 0.474RT - 0.008SA_{ij}} \leq e^{-2.615}
\]

Where, \( T_{ij} \) = Total travel demand by public transport between \( i^{th} \) and \( j^{th} \) zone,
\( MGC \) = Minimum Generalized travel cost in Rupees to travel between \( i^{th} \) and \( j^{th} \) zone.
\( SA_{ij} \) = Product of square roots of DSD’s area between \( i^{th} \) and \( j^{th} \) zone.

The Figure 01, shows relationship of the four different models that have been calibrated to estimate total passenger matrix to travel between DSD’s.
Figure 01 illustrates the two alternative ways to estimate inter DSD total demand using the common variables. One alternative is the aggregation of rail ordinary ticket and season ticket models together with the bus model as against the second alternative is a direct model.

VALIDATION OF MODELS

The process of model validation is an important step intended to check the accuracy of the model predictions with respect to actual field observations. The data set used for the analysis had a number of incomplete data for certain DSDs. These DSDs were not used in the model calibration, but the available data was used for the model calibration. Table 02 shows the comparison between the predictions of the models as against the actual observations for a set of origin destination pairs selected randomly from the larger base of 528 cases.

<table>
<thead>
<tr>
<th>DSD</th>
<th>Bus</th>
<th>Rail(^0)</th>
<th>Rail(^S)</th>
<th>TPTDM</th>
</tr>
</thead>
<tbody>
<tr>
<td>FROM</td>
<td>TO</td>
<td>OBSER</td>
<td>PREDIC</td>
<td>OBSER</td>
</tr>
<tr>
<td>Wattala</td>
<td>Panadura</td>
<td>451</td>
<td>562</td>
<td>6</td>
</tr>
<tr>
<td>Colombo</td>
<td>Katana</td>
<td>15181</td>
<td>11534</td>
<td>524</td>
</tr>
<tr>
<td>Kesbewa</td>
<td>Nugegoda</td>
<td>12894</td>
<td>14145</td>
<td>0</td>
</tr>
<tr>
<td>Colombo</td>
<td>Hanwella</td>
<td>11459</td>
<td>5808</td>
<td>248</td>
</tr>
<tr>
<td>Kelaniya</td>
<td>Horana</td>
<td>413</td>
<td>380</td>
<td>0</td>
</tr>
<tr>
<td>Beruwala</td>
<td>Kalutara</td>
<td>9345</td>
<td>4118</td>
<td>344</td>
</tr>
</tbody>
</table>

Where: OBSER = Actual observation of travel between \(i^{th}\) and \(j^{th}\) zone.
PREDIC = Model predictions for travel between \(i^{th}\) and \(j^{th}\) zone.
TPTDM = Total Public Transportation Demand Model.

In most cases used in the comparison it was found that the bus model under predicted. This may be due to errors in waiting time especially for longer trips. In the case of rail models, the product of rail catchment area between DSD’s appear to return inconsistent outputs due to the higher weightage for geographically large DSDs. For example, in the case of the Colombo – Hanwella case, since Colombo has a small DSD area and Hanwella has a very large DSD area, the product of areas show and inconsistency with respect to the number of railway stations. As such, many rail trips are under estimated. To avoid this weakness in the model, the variable that captures rail accessibility needs to be further improved.

Total demand estimation by public transport was done using both alternatives. It was found that the total public transportation model (TPTM) predictions vary by up to 10% from actual observations and is hence recommended for application in demand estimation studies.
CONCLUSIONS

The main conclusions that are reached in this study are:

- Four models for bus and rail travel have been successfully calibrated to a common format and with common independent variables.
- Passenger trips demand is found to be strongly determined by the demographic and socioeconomic characteristics and is not particularly associated with land use characteristics.
- More inter trips are represented by the product of employed population rather than population of population density as is usually found in travel demand models.

REFERENCES


Kumarage, A.S.,(1990), Intercity Travel Demand Modeling, University of Calgary, Alberta, Canada.


SPSS Inc., (1999), Statistical Package for Social Scientists: Release 10.0, USA.

Wachs, M., Taylor, B., Levine, N. and P. Ong (1993), The Changing Commute: A Case Study of the Job Housing Relationship Overtime, Graduate School of Architecture and Urban Planning, University of California, Los Angeles, USA.


Annexure 01: Divisional Secretary Divisions of the Colombo Metropolitan Region

Population Density in Western Province

Legend
Population Density
- 0-500
- 500-1000
- 1000-2500
- 2500-5000
- 5000-7500
- 7500-10000
- 10000-50000

Transportation Engineering Division,
University of Moratuwa
TransPlan Database